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Modular Pumped Hydro for Grid Energy Storage

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AET Summer Student Seminar Series

June 26, 2013

LAUR-13-xxxx

Why Energy Storage?
Best Utilize Our Water and Fuel Resources.

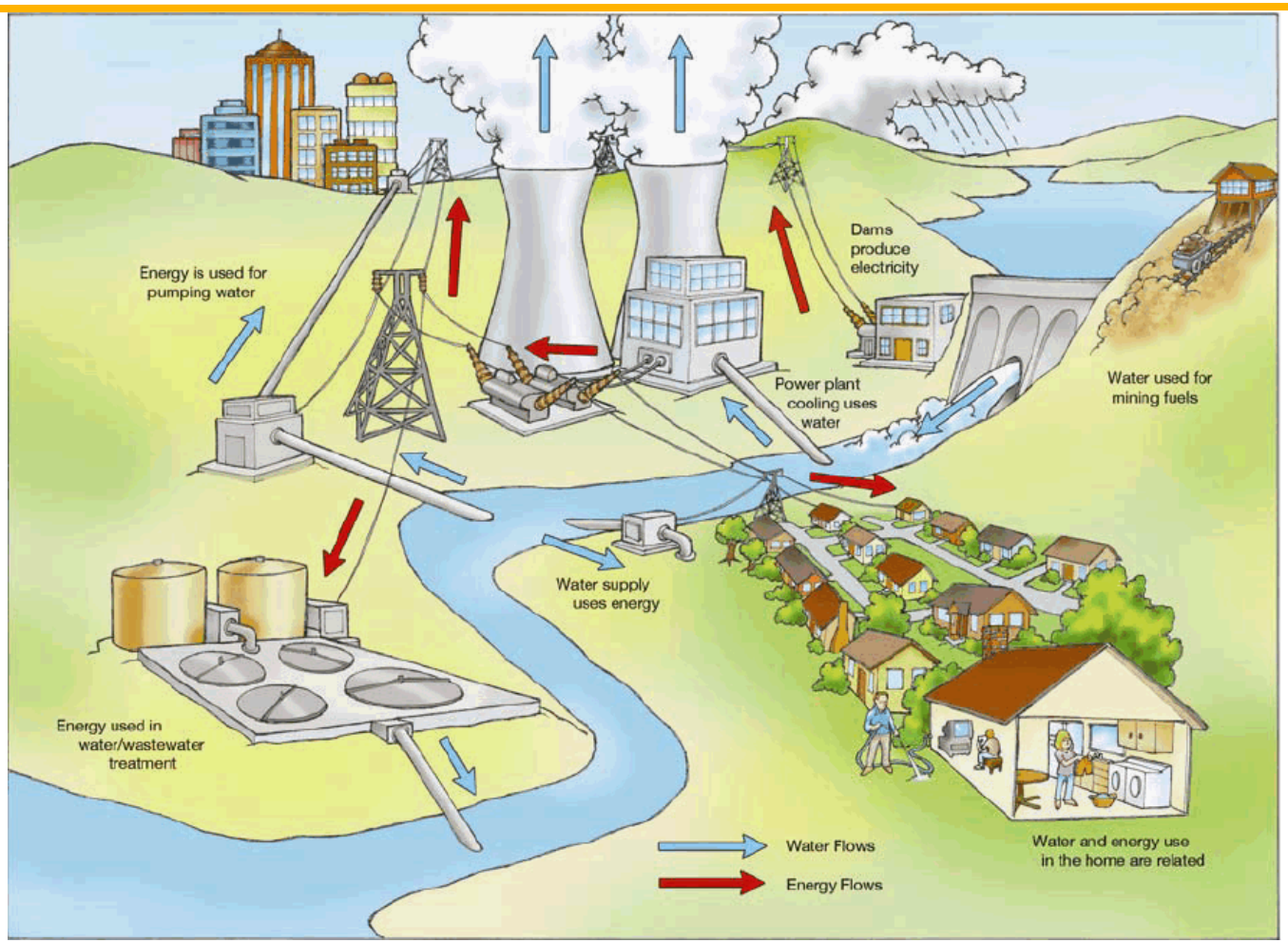


Figure I-1 of "Energy Demands on Water Resources, A Report to Congress", US DOE, December 2006.

The Holes That We Dig and Must Fill.
(It's Mind Boggling!)

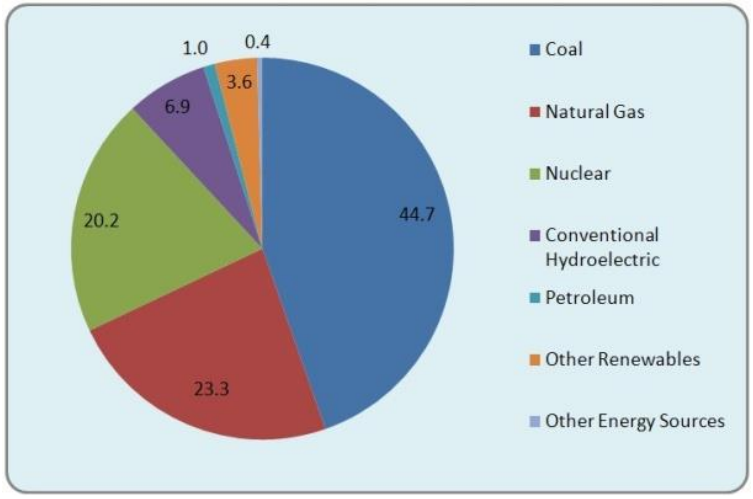
- OIL: 85 million barrels/day
- NATURAL GAS: 260 billion cubic feet/day
- Coal: 14 million tons/day

- OIL: $1.1 \times 1.1 \times 1.1$ cubic miles per year
- As liquid: $1.3 \times 1.3 \times 1.3$ cubic miles per year
- COAL: $1.0 \times 1.0 \times 1.0$ cubic miles per year

Slide 16 of presentation "Will There be Enough Energy for All in the 21'st Century", LA-UR-06-2989, 2006, by Rajan Gupta.

Total US Fuel(Electric Gen) and Water Usage (More Mind Boggling)

% Net US Fuel Consumption (2009) Electric Generation



US Energy Information Administration/Electric Power Monthly, March 2010, Table ES1.B for 2009, for all sectors.

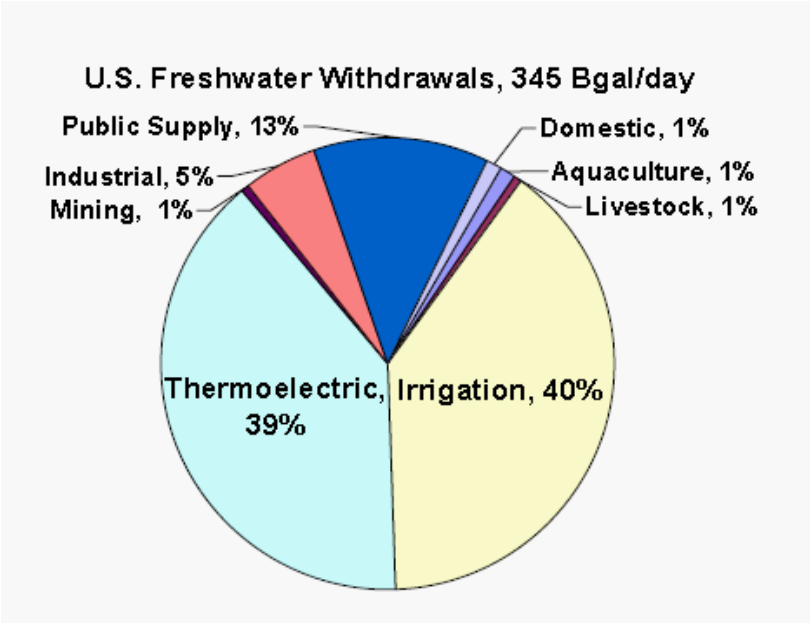
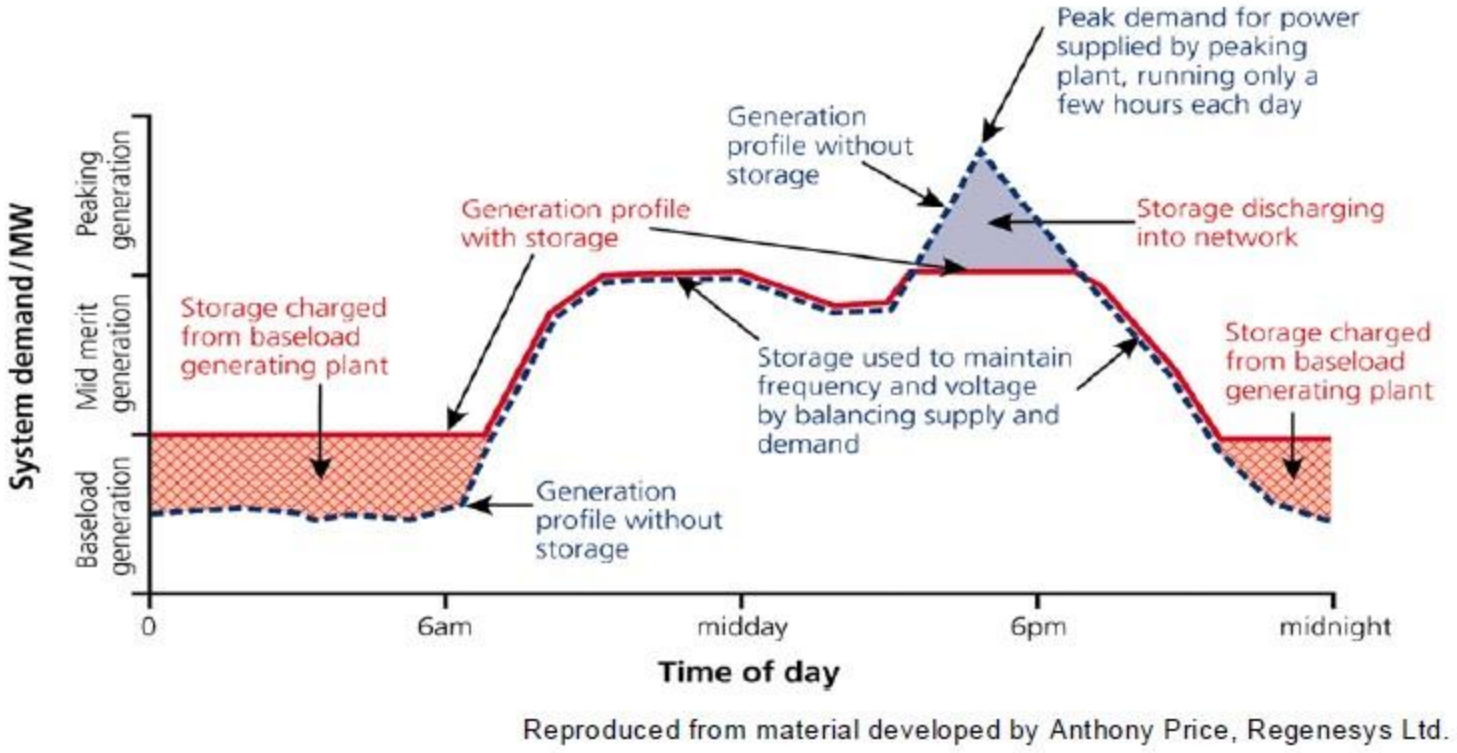


Figure II-1 of "Energy Demands on Water Resources, A Report to Congress", US DOE, December 2006.

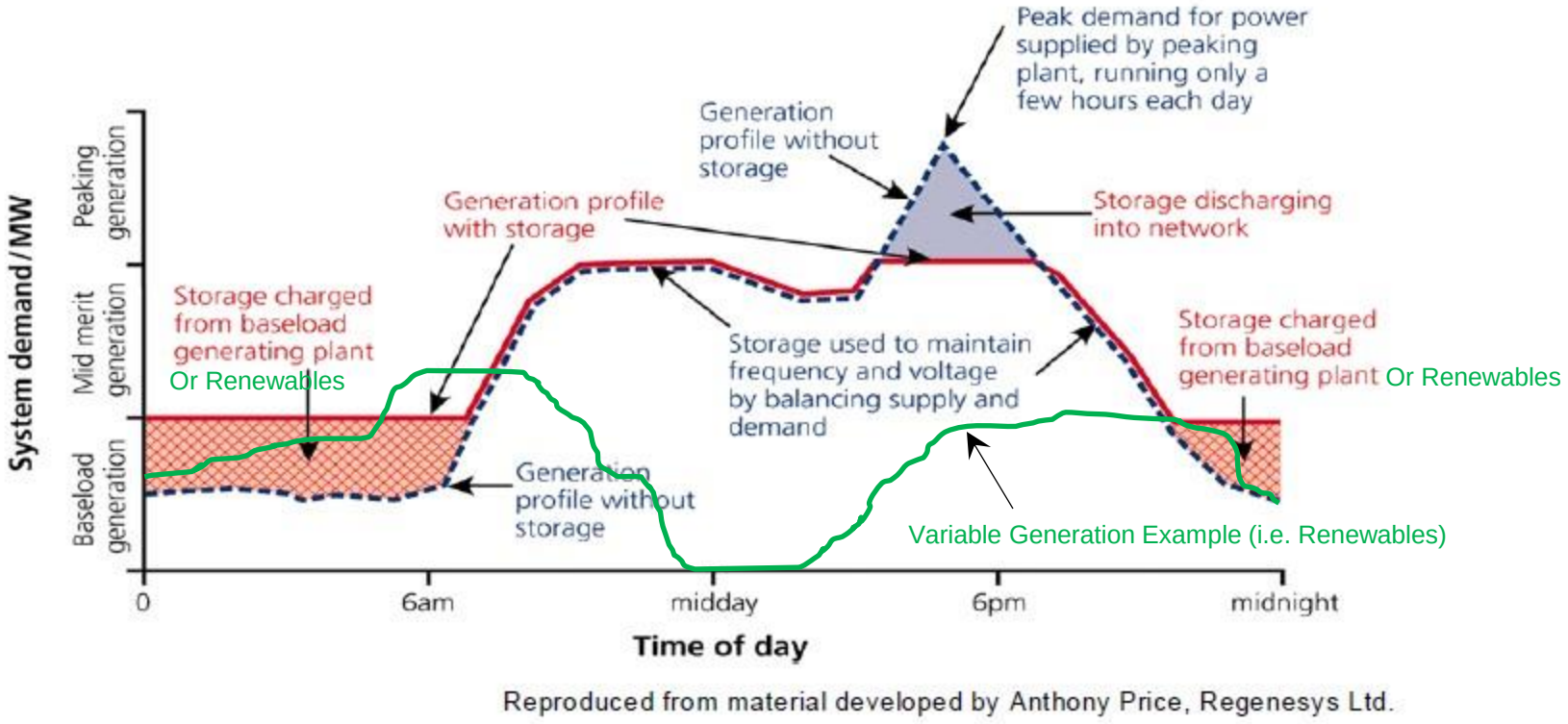
3.95 x 10^9 MW-hrs across all sectors

How Does Energy Storage Fit In? Variable/Uncertain Generation Increased Need for Grid Flexibility



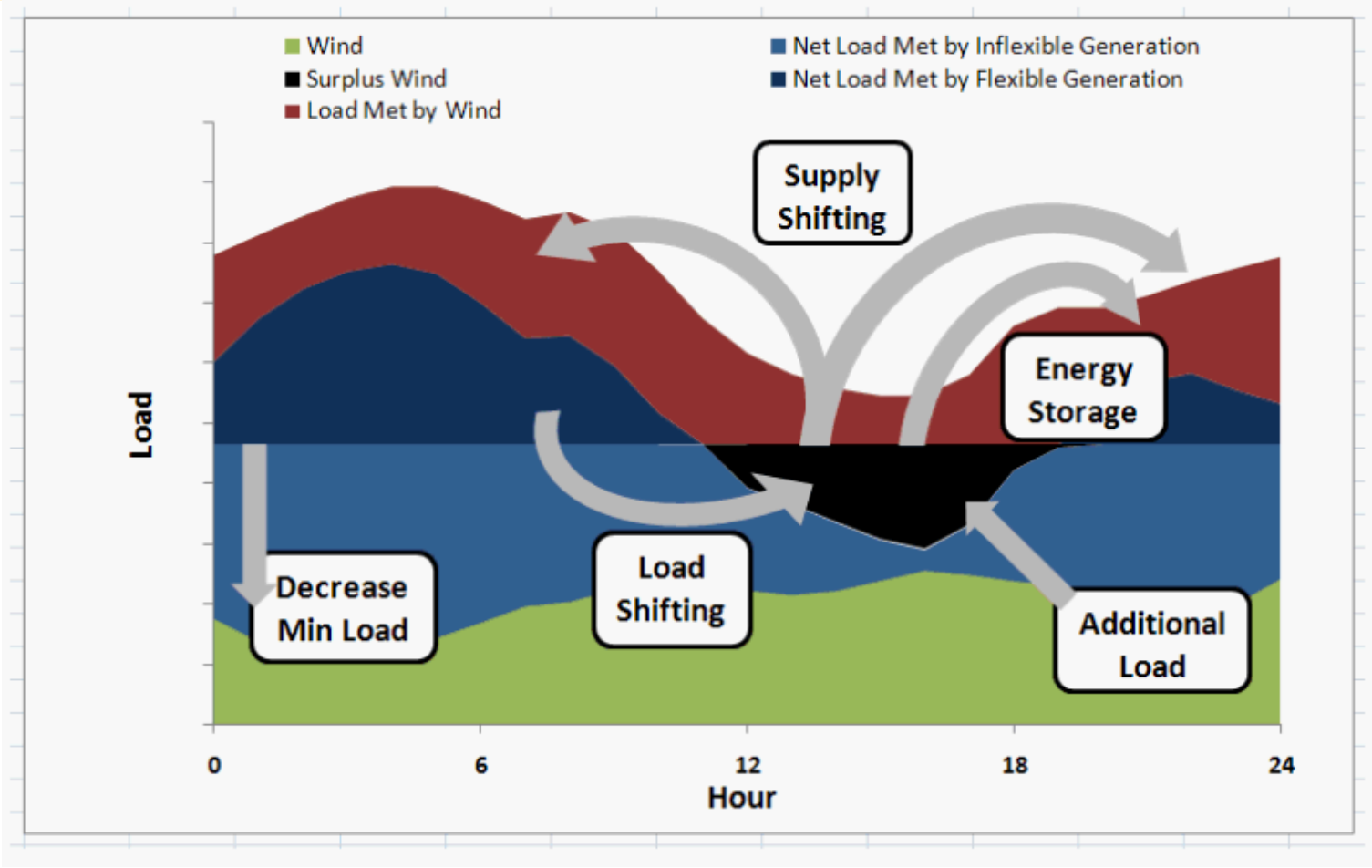
Adapted From Figure on pg. 7 "Load Profile for a Large Scale Energy Storage Facility," from "Energy Storage—The Missing Link in the Electricity Value Chain, An Energy Storage Council White Paper," copyright May, 2002.

How Does Energy Storage Fit In? Variable/Uncertain Generation Increased Need for Grid Flexibility



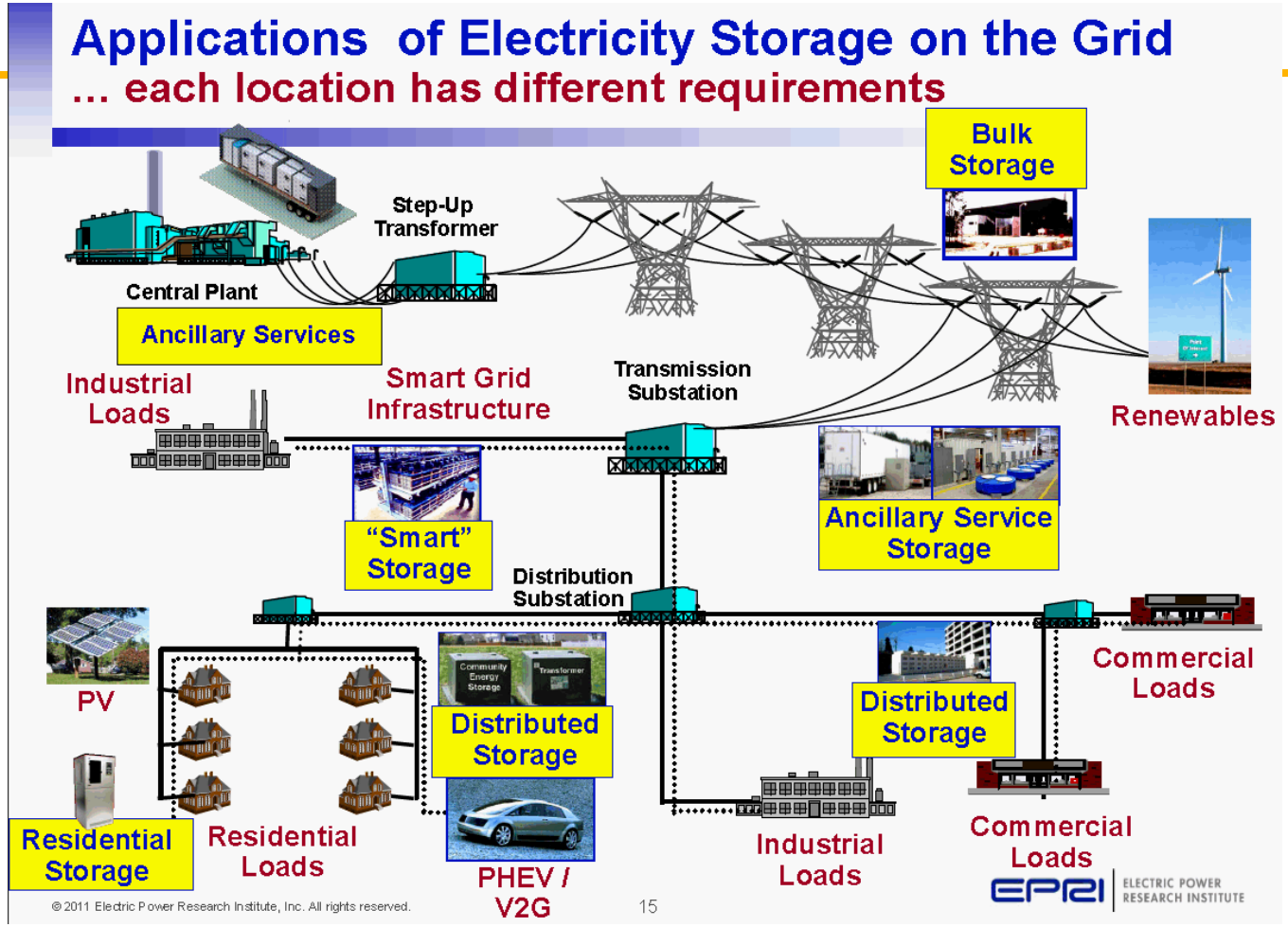
Adapted From Figure on pg. 7 "Load Profile for a Large Scale Energy Storage Facility," from "Energy Storage—The Missing Link in the Electricity Value Chain, An Energy Storage Council White Paper," copyright May, 2002.

To Be Fair……..
There are other ways to provide grid flexibility
(It's All About Economics and Risk!)

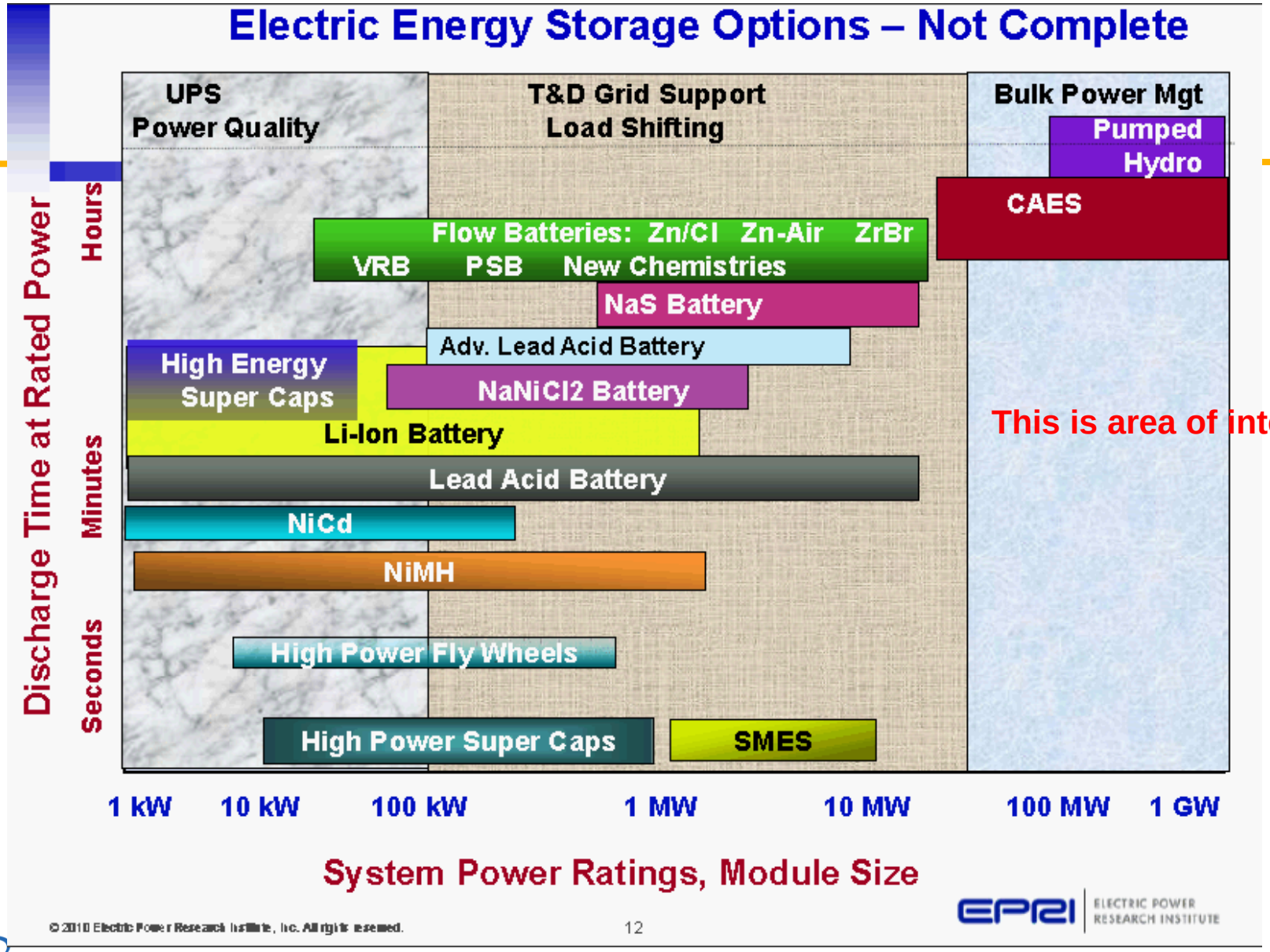


Paul Denholm et. el, "The Role of Energy Storage with Renewable Electricity Generation", Fig 4.10, Technical Report NREL/TP-6A2-47187, January 2010.

We'll Continue with Energy Storage



Slide 15 from presentation by Aiden Tuohy and Dan Rastler of Electric Power Research Institute, "Wind Integration And Energy Storage", MISO Energy Storage Workshop, June 29, 2011.



Slide 15 from presentation by Aiden Tuohy and Dan Rastler of Electric Power Research Institute, "Wind Integration And Energy Storage", MISO Energy Storage Workshop, June 29, 2011.

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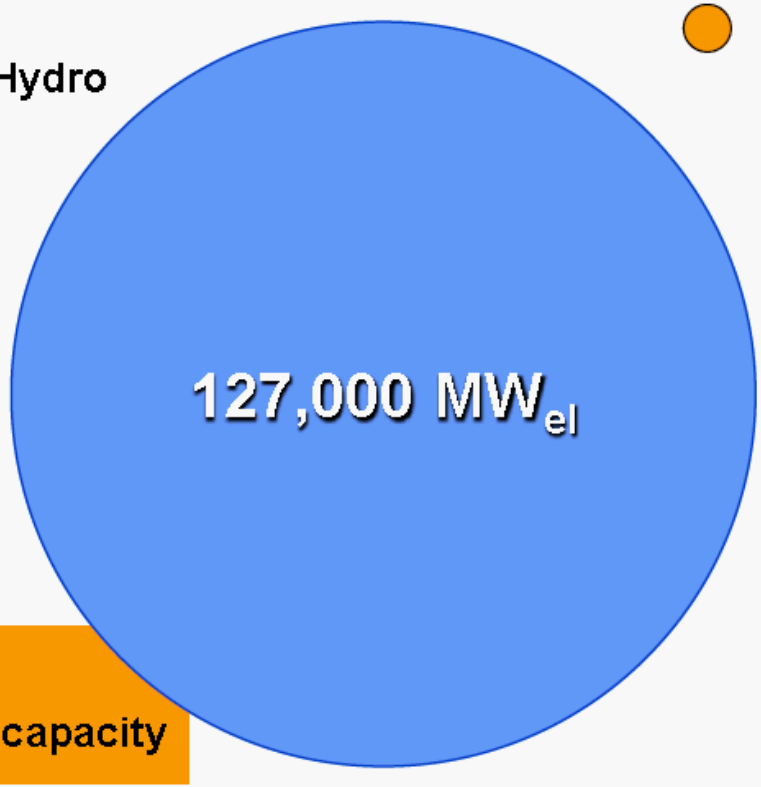
Today, Energy Storage Penetration is Actually Very Small

Worldwide installed storage capacity for electrical energy



Over 99% of total storage capacity

- Compressed Air Energy Storage **440 MWs**
- Sodium-Sulphur Battery **316 MWs**
- Lead-Acid Battery **~35 MWs**
- Nickel-Cadmium Battery **27 MWs**
- Fly Wheels **< 25 MWs**
- Lithium Ion Battery **~20 MWs**
- Redox-Flow Battery **< 3 MWs**

Source: Fraunhofer Institute, EPRI

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EPRI ELECTRIC POWER RESEARCH INSTITUTE

Slide 20 from presentation by Aiden Tuohy and Dan Rastler of Electric Power Research Institute, "Wind Integration And Energy Storage", MISO Energy Storage Workshop, June 29, 2011.

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Growth in Pumped Hydro Faces Challenges

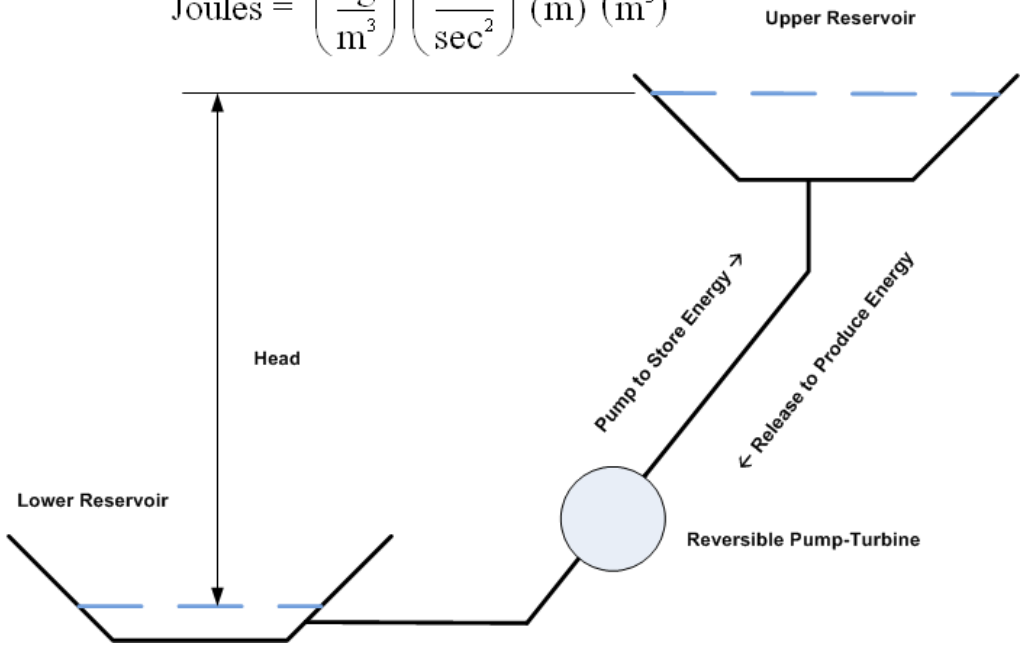
Hoover Dam from Wikipedia.

Design of Modular Pumped Hydro (MPH)
80% Efficient (Full cycle)

- Up 1 GW-hr electric storage
- Closed-loop pumped hydro technology
- "Smart sited" near existing renewable production & transmission lines, away from endangered species, environmentally sensitive areas
- Permit/Build/Commission < 4 yr
- < 20 acres reservoirs
- 1.1 $/W = Total Cost
- Produce no emissions or solid waste
- Zero net water consumption

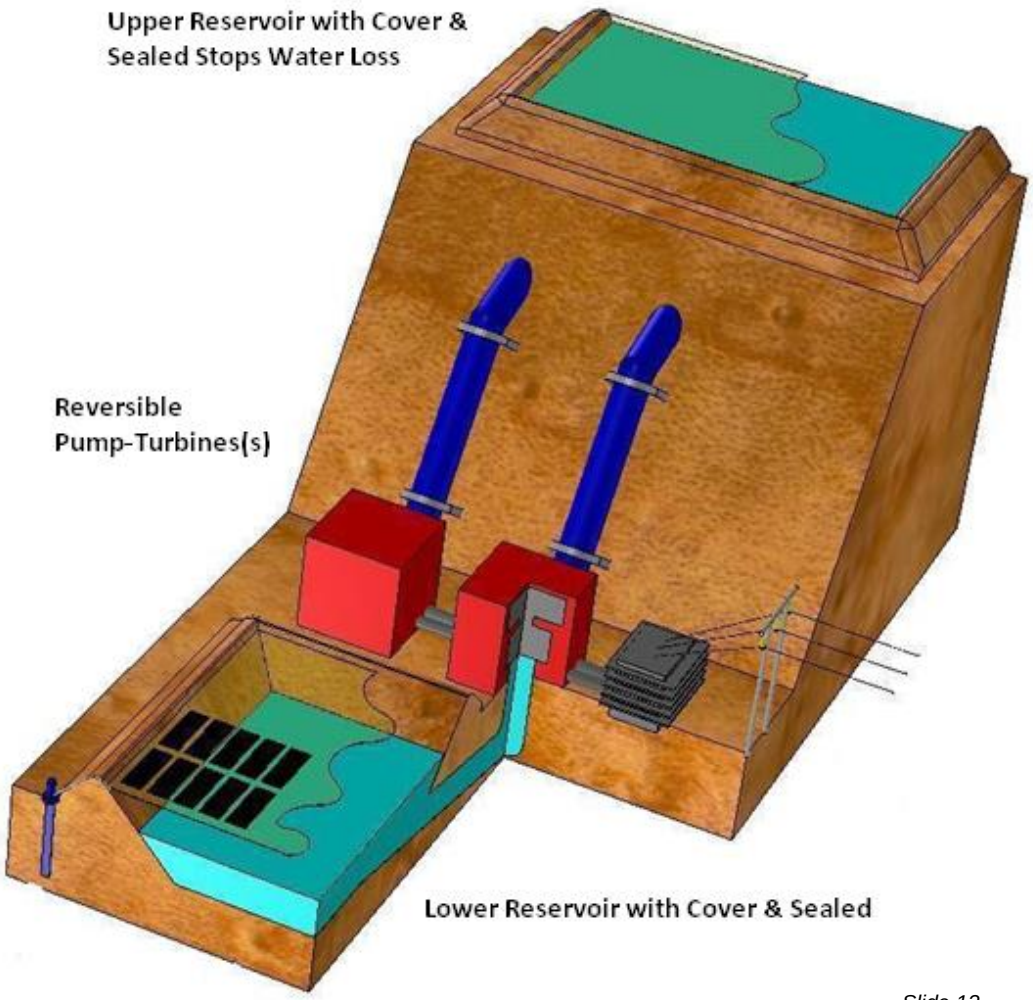
$$\text{Produced Energy} = (\text{efficiency})\ (\text{density})\ g\ (\text{head})\ (\text{volume})$$

$$\text{Joules} = \left(\frac{\text{kg}}{\text{m}^3}\right)\left(\frac{\text{m}}{\text{sec}^2}\right)(\text{m})\ (\text{m}^3)$$

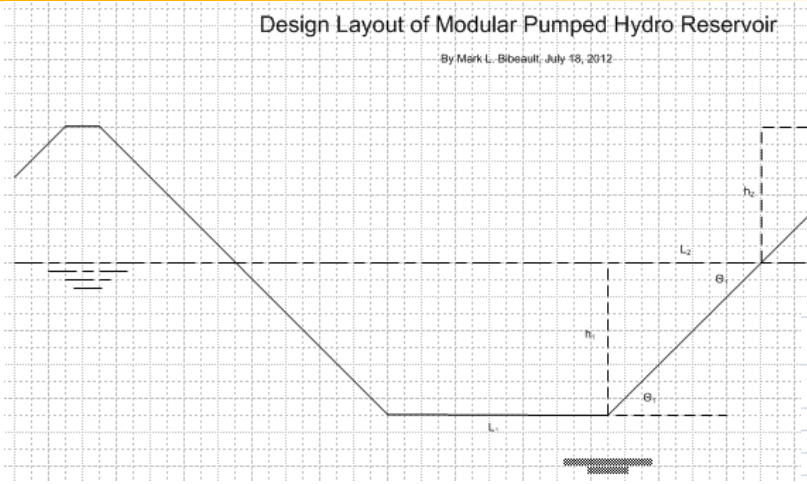


Modular Pumped Hydro(MPH) Details

- **Design**
  - Ring embankment, earth fill
  - Cover & line
  - Leakage recycled
  - Catch rainfall
  - Complimentary solar siting
- **30 to 300 m head**
- **30 to 300 MW power rating**
- **< 12 hrs discharge**
- **Each reservoir**
  - 1000 acre-ft volume
  - 10 acres surface area
  - Locate flat top mtn. w/flat basin



Behind the Scenes Work

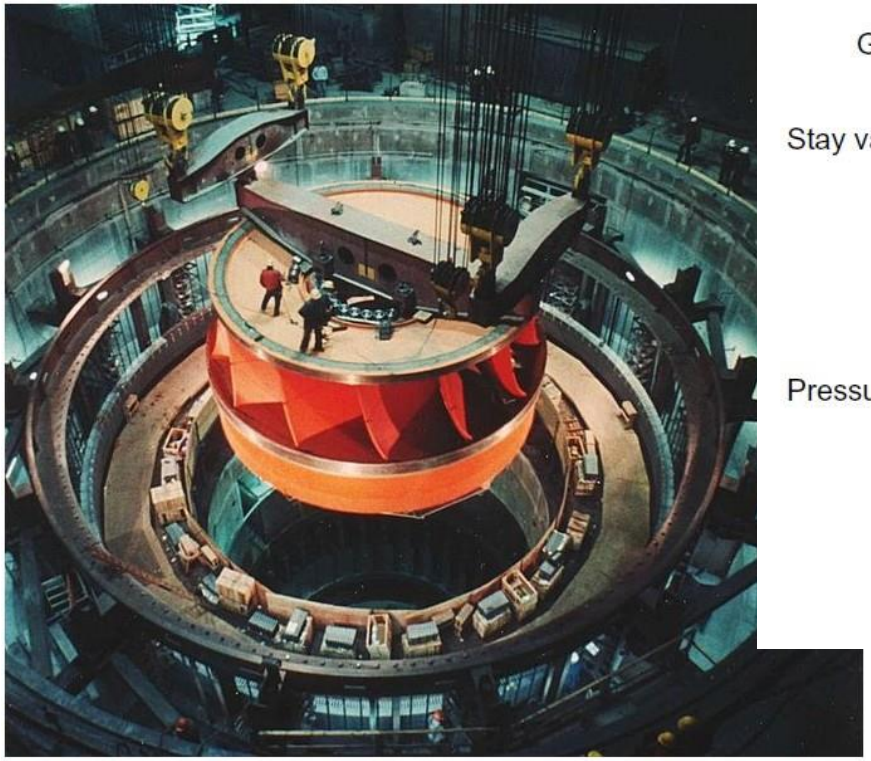


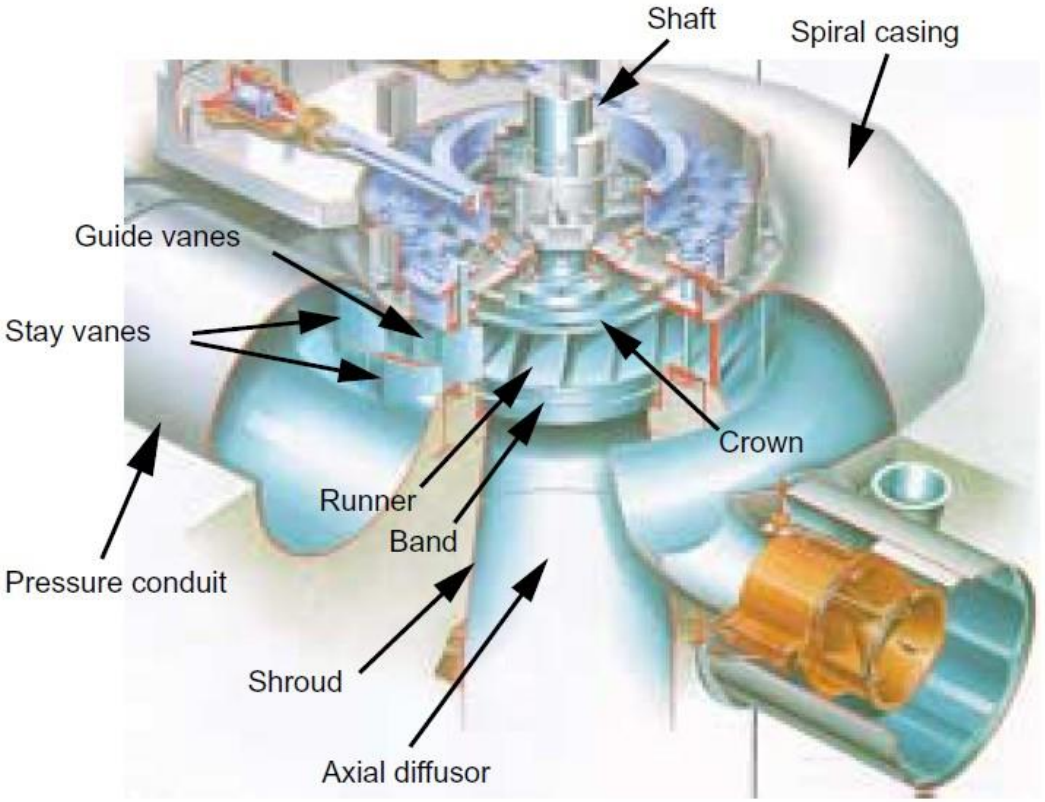
Financial Model

WF Expenses =	26	$/MW-hr		Payback Determination for Adding A Mopular Pumped Hydro (MPH) Energy Storage Facility				
ES Expenses =	10	$/MW-hr		By Mark L. Bibeault, AET-1				Default assumption: store energy for 20 hrs eac
ES Full Efficiency =	80.0	%		Last Updated 1/31/2013				Wind Farm is 200 MW at full power. Energy Stor
		Wind Production						
		Average MW	hrs	Type of Release	Avg. Power During Release (MW)	Daily Production (MW-hrs)	Quartely Production (MW-hrs)	Orig
Qtr 1 = Spring	Store	60	20	ES Energy Release	240	960	76,800	
	Rel	180	4	WF Directly Released	180	720	57,600	
	# days =		80	Total Energy Released	420	1,680	134,400	
Qtr 2 = Summer	Store	50	20	ES Energy Release	200	800	64,000	
	Rel	80	4	WF Directly Released	80	320	25,600	
	# days =		80	Total Energy Released	280	1,120	89,600	
Qtr 3 = Fall	Store	60	20	ES Energy Release	240	960	76,800	
	Rel	90	4	WF Directly Released	90	360	28,800	
	# days =		80	Total Energy Released	330	1,320	105,600	
Qtr 4 = Winter	Store	50	20	ES Energy Release	200	800	64,000	
	Rel	110	4	WF Directly Released	110	440	35,200	
	# days =		80	Total Energy Released	310	1,240	99,200	
Estimated Duty Cycle	24.47	%						
				Yearly Total	ES Energy Release	281,600		
					WF Directly Released	147,200		
					Total Energy Released	428,800		

View of Reversible Francis Turbine/Pump

One of 6 turbines for Grand Coulee Dam project, Columbia River, State of Washington, each rated at 750 MW, from the Bureau of Reclamation via Wikipedia.





From Fig 1.3 of Thesis for Doctor of Philosophy, "Numerical Investigations of Turbulent Flow in Water Turbines", Hakan Nilsson, Department of Thermo and Fluid Dynamics, Chalmers University of Technology, Goteborg, Sweden, 2002. Picture courtesy of GE Energy (Sweden) AB.

Program Development

- **Lots of meetings**
  - Tech Transfer
  - Energy Council
  - Program Managers
- **Mentor Program**
- **Oak Ridge National Laboratory**
- **Discussions with Utilities**
  - Jemez Electric/Tri-State
- **Discovery Day**

Modular Pumped Hydro (MPH)
Example Case/Cost Study for Discovery Day

- **Location: 200 MW NM Wind Center, Vaughn, NM**
- **Store energy 18 hrs per day, release to grid 6 hrs per day (during peak demand)**
- **25% Wind Farm operational cycle**
- **H = 400 ft (122 m), Reservoir Volume = 1639 acre-ft**
- **Energy Storage Power = 150 MW**
- **Total energy released = 219 MW-hrs***

Table 1 : Financial Results (Total = 153.1 $M)

Item	Result
Normalized Cost ($/W)	1.02
Normalized Profit ($/MW-hr)	48.63
Yearly Profit ($M)*	10.83
Total Cost ($M)	153.1
Interest (%)	4.00
Monthly Payment ($M)	0.9024
Payback (yrs)	20.87

*for energy storage facility

Comparison of Gas Turbine and MPH (150 MW)

Parameter	Gas Turbine	MPH
Capital Cost ($/W)	0.7	1.03
Operating Cost(mills/kW-hr)	0.045	0.01
Total Capital($M)	105	153.1
20 Year Operational Cost	197.1	43.8
Total Cost ($M)	**302.1**	**196.9**
Net Efficiency (%)	40	80
Fuel Costs	Variable	Stable
Ancillary Services	Some	Full
Net Water Usage	Yes	None
Startup to Full Power (no warm standby)	< 30 min	< 60 sec

Where Do We Go From Here?
A Work In Progress….

- **Collaboration with NMSU**
- **Non Disclosure Agreements**
- **Preliminary Site Selection**
- **Verify Financials**
- **Perform A Feasibility Study**
  - 1 year+ at $1.5 -- 2M
  - Includes Utilities, State Universities, Contractors
  - Team members:
    - Geotechnical Engineering
    - Pumped Hydro
    - Electrical Engineering
    - Grid Modeling
    - Engineering Economics
    - Systems Engineering & Logistics
    - Permitting Policy & Regulation